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A conceptual framework for linking worker and organizational needs to data and information requirements

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Abstract

Data and information intensiveness is increasing at the shop floor in the manufacturing industry, which leads to the fragmentation of tasks as the needed information is often scattered in different places. The challenge is to provide correct and right amount of information both to increase job satisfaction of workers and to increase productivity. The objective of this study is to identify what kind of manufacturing data, information and intelligent knowledge is needed by workers at the shop floor, and to identify the requirements when opening the knowledge flows between the shop floor and management processes. As a results of the study, a conceptual framework is created to link workers' and organizational needs to data and information requirements. The framework identifies information and knowledge flows from and to required human-machine interfaces. This study also highlights the link between work processes at the shop floor to the innovation and organizational learning processes of manufacturing companies.

Keywords: worker needs; organizational needs; shop floor; data and information management; knowledge flows; organizational learning; Internet of things, automotive industry

1. Introduction

The workers and organizations in the automotive industry are overloaded with data and information and may paradoxically simultaneously lack the information they need to work effectively. The challenge is to provide the right information to the worker at the right time, and to both avoid information overload yet provide enough information in order to increase productivity. The large amounts of data a manufacturing factory gathers, processes and stores contains information that can be directly valuable to workers, but it has to be transformed by using web-based social, semantic and big data technologies into an intelligent information system [1]. According to Lee et al., [2], data is not useful before it is processed in a way that provides context and meaning that can be understood by the right workers. By giving workers usable tools with dedicated worker-computer interfaces that allow them to find, use and contribute to that information on their terms, both the effectiveness in doing their jobs as well as aspects of their job satisfaction and motivation can be increased. Additionally, the image of manufacturing industry as an attractive employer can be improved, since manufacturing work is often perceived as repeating routine tasks, which can easily lead to workplace boredom and poor job satisfaction [3, 4]. When improving the motivation and job satisfaction of workers on the shop floor, it can be assumed that the organizational requirements, i.e. increased productivity, improved quality and costs savings, are supported as well.

Chen et al. [5] have presented an overview on the basic concepts of enterprise integration since the middle of the 80s. They have divided the different approaches into e.g. physical integration (interconnection of devices, NC machines via computer networks), application integration (integration of software applications and database systems), and business integration (co-ordination of functions that manage, control and monitor business processes). Several enterprise architecture frameworks have been developed, such as the Computer Integrated Manufacturing Open System Architecture (CIMOSA) [6] or Purdue Enterprise Reference Architecture (PERA) [7]. These developments in turn have progressed partially towards standardization under the ISA-95 framework where a higher degree of vertical integration is pursued, but not yet generally achieved due to implementation challenges [8]. Recent trends are moving from architectures for enterprise integration to the development of frameworks for interoperability, such as ebusiness and eGovernment related interoperability [5]. However, previous research has focused more on developing different kinds of integration models, where the focus has been in the top-down information flows from top management to the shop floor. According to Chen et al. [5, p. 658]: "*Enterprise architecture development should have also been carried out bottom up from best practices and not only the top down approach as most of the past works adopted*".

The objective of this study is to identify what kind of manufacturing data, information and when is needed by workers at the shop floor. As a theoretical contribution, a conceptual framework is created to link workers' and organizational needs to data and information requirements. In addition, this study identifies requirements when opening the knowledge flows between the shop floor and management processes. Thus, this study also highlights the link between work processes in a shop floor to the innovation and organizational learning processes of manufacturing companies. This study has been carried out in the context of the European research project FACTS4WORKERS in which the objective is to develop and demonstrate workplace solutions that support the inclusion of increasing elements of knowledge work on the factory floor. It is part of the theoretical background analysis for the project by bringing up existing concepts, offering new insights and broadening the current thinking of worker and organizational needs.

The rest of the paper is structured as follows. Section 2 reviews the literature related to manufacturing data and information, and aspects of learning in workplaces in digital manufacturing environments. Section 3 describes the research approach of this study. Section 4 introduces the conceptual framework for knowledge flows and performance improvements, and Section 5 discusses the findings and concludes the paper.

2. Related research

2.1. Manufacturing data and information in digital manufacturing environments

Knowledge intensiveness is increasing in almost all types of work, and this leads to the fragmentation of tasks as the needed information is often scattered in different places. In modern digital manufacturing environments, the volume of data grows at an unprecedented rate, using e.g. barcodes, sensors, vision systems, which can be related to design, products, machines, processes, material, inventories, maintenance, planning and control, assembly, logistics, performances etc. [9]. However, just connecting sensors to a machine or machine-to-machine connections will not give users the insights needed to make better decisions [2]. The basic definition of a manufacturing information system can be enhanced with 5C functions:

- Connection (sensor and networks),
- Cloud (data on demand and anytime),
- Content (correlation and meaning),
- Community (sharing and social), and
- Customization (personalization and value) [2].

According to Browne et al. [10], two main sources of industrial process knowledge are job floor personnel and operational data, which are supported by secondary sources such as technical specification, written shop floor practices and operating theory. Different data mining techniques have been used to extract knowledge from shop floor data, and human knowledge is captured through knowledge-elicitation with many established techniques, such as interviews and observations. Browne et al. [10] introduced a method to fuse knowledge-elicitation and data mining in order to obtain relevant shop floor knowledge more efficiently and effectively. Zhang et al. [11] have identified the typical challenges that manufacturing companies currently face; these are lack of timely, accurate and consistent information on manufacturing things (resources) from shop floor front lines. They have presented an overall real-time information capturing and integration architecture of the Internet of manufacturing things (IoMT) to provide a new paradigm to extent the Internet of things (IoT) to the manufacturing field [11]. Taisch et al. [12] argue that in the next decade IoT will dominate ICT solutions on a shop floor level, and machinery, robots, lines, items and operators will be acting in a strong connected, decentralized and autonomous network at the shop floor. In addition, Taisch et al. continue that from the ICT perspective, the shop floor will be dominated by easy to plug-and-work devices and seamless exchange of information.

Due to growing customization and reducing lot sizes in production and complex assembly across the entire automotive value chain (e.g. in car interior manufacturing or production of 3D steel and plastic components) operators and production workers need to deal with a growing number of specified and quickly changing information from various sources, while effective working requires two hands for operation. However, workers even in the digital age need to rely on paper checklists generated from MES/ERP systems, in order to receive exact job descriptions or orders. In this situation operators may be irritated by information overload while fulfilling the specified working task. Context-relevant information displayed in the line of sight, without media brakes and a seamless interaction across different IT tools becomes crucial for smooth operation and avoidance of cognitive overload. [13]

Product and process information is often stored, processed and communicated in different ways by ICT applications; technical data is managed e.g. in Product Data Management systems (PDM), business information is managed e.g. in Enterprise Resource Planning systems (ERP), and manufacturing information in e.g. Manufacturing Execution Systems (MES). Many companies that have implemented a MES looked for detailed, timely and accurate information on actual costs, current order status, as-built products and capacity availability at the production level [7]. In Fig. 1, there are the standards which are commonly accepted to allow information exchange between ERP, CAD, PDM and MES applications. [14]

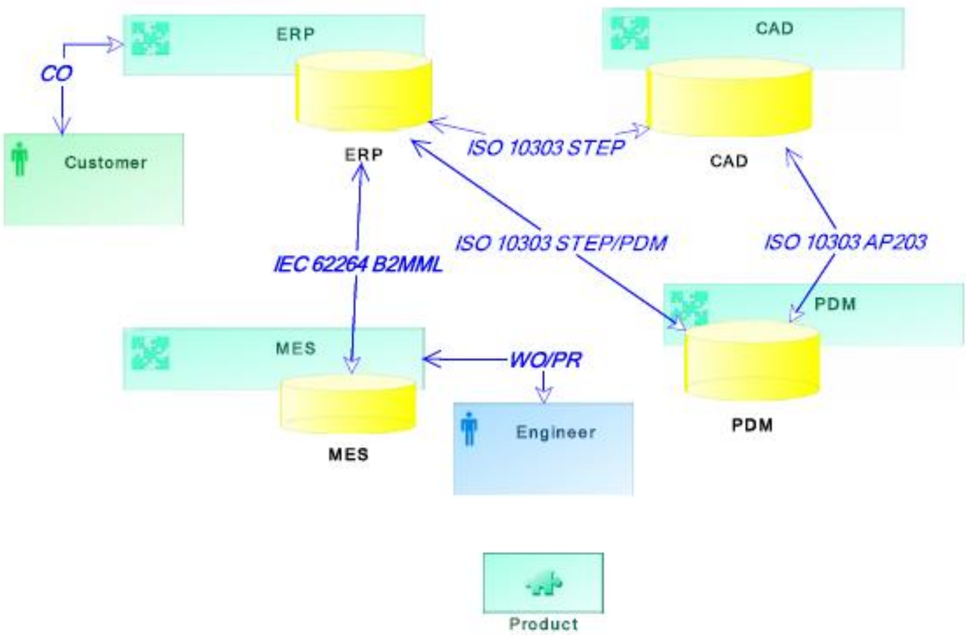

Fig. 1. Standards within a manufacturing enterprise [14, p. 337]

The ANSI/ISA-95.00.03-2005 [15] Standard (ISA-95) has dropped the MES term, favoring the broader concept of Manufacturing Operations Management (MOM). This concept has a wider scope of meaning, including multiple plants and each of the operational areas of manufacturing, from production to warehouse, maintenance, scheduling, quality, material handling and labor processes. ISA-95 Standard comprises five levels (0-4), each representing a level of manufacturing production, from shop floor to corporate planning. [8] The ISA-95 systems hierarchy model is presented in Fig. 2. The ISA-95 standard is designed for top-down information flow [16].

Automotive manufacturing companies are faced with a vast set of demands. Those demands may be very strict and detailed and non-compliancy to any of them may lead to a loss or termination of business deals. Therefore, whenever any unexpected, unplanned or unsuccessful situation on the shop-floor arises, this has a negative impact on the enterprise. In a Smart Factory [17, 18] an intelligent, self-learning optimization process with the use of an advanced system for collecting product/resources/process data, IT-technology and diagnostics tools and a proper data presentation system with a user-friendly interface for the shop-floor employees is required. The services involved, whether corresponding to material activities carried out by people and/or machines or data-bound processes, are often arranged in a manual way and seldom changed or revised. Automation can allow more efficient operations that are dynamically evolving according to actual needs. Their implementation will aid manufacturers to acquire a tighter intelligent and interactive control over workplace, work safety, active protection of workers and economic benefits and enable them to actively monitor and respond to any problems that might arise regarding the machinery and devices they use. [13]

The basic concept of the fusion model, introduced by Ishii [19], clarifies the functions of both users' needs assessment and technology assessment for generating new creative ideas. Different forms of the fusion model have been generated for different purposes and applications in industry. For example a viable product idea can be considered to be a fusion of a user need and a technological opportunity as well as a new work design can be considered to be a fusion of workers' needs and company's needs, see Fig. 3. Ishii has also developed and proposed models and methods to analyze information behavior in the assessment of users' or workers' needs. The concept of information behavior includes the structure and operation of collecting information, using information and making decisions [19]. In this paper, assessment of worker and organizational needs linked with the means of new Internet of things technologies, points out new application needs for the fusion concept.

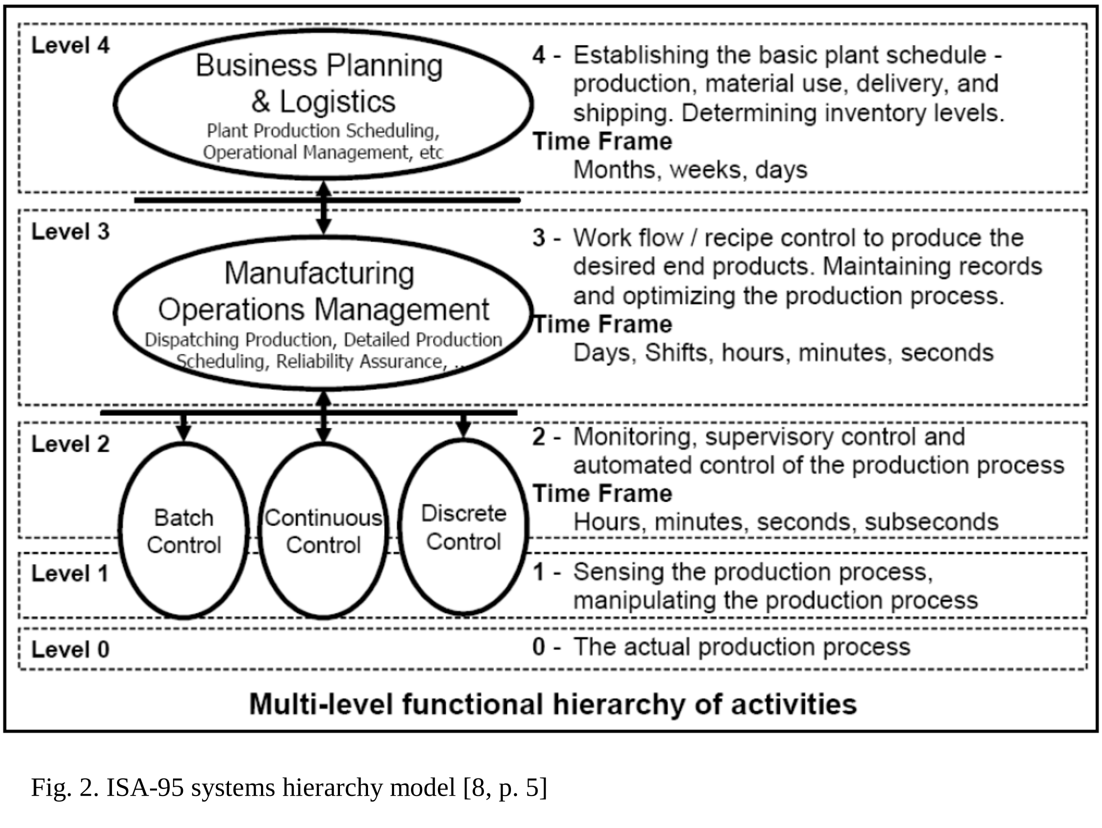

Fig. 2. ISA-95 systems hierarchy model [8, p. 5]

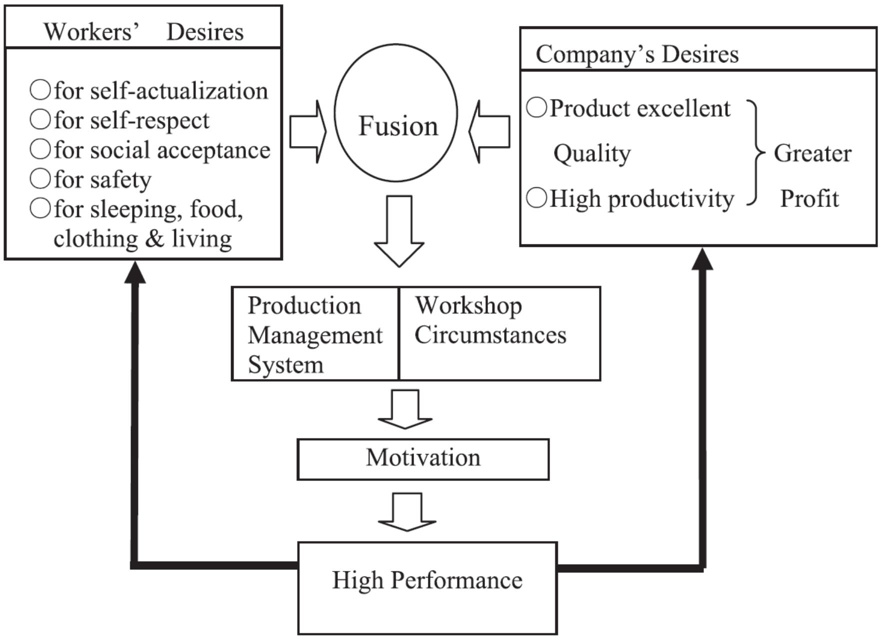

Fig. 3. The fusion concept to harmonise desires of worker and company [19, p. 7324]

2.2. Learning perspective

The pursuit towards more complete management of manufacturing data and information is not motivated only by simple optimization of the extant processes. While successfully designing and implementing a control, guidance and management system able to vertically integrate the enterprise information flows would imply a substantial step-change in productivity, the true value of such a system is created through dynamic effects, namely learning mechanisms. The knowledge-based view of the firm [20] posits that the firm is at its heart an institution for integrating knowledge, and value is created by integrating the specialist knowledge residing in individuals into goods and services. The role of management, thus, is to provide an environment and sufficient coordination for enabling such knowledge application and integration, or knowledge conversion [21]. Following this viewpoint, the main benefits of unimpeded utilization of the knowledge flows within the manufacturing enterprise comes from three dynamic processes of continuous knowledge codification, integration and application:

- On the worker level improvement results from individual [22] and organizational learning [23]
- On the organizational level improvement results from business process re-engineering and optimization [24]
- On the management level improvement results from (worker-driven) innovation [25]

The improvements do not limit only to productivity gains, but also include gains towards human-centric objectives, such as job satisfaction, engagement and motivation, social status, fostered community, and safety and wellbeing of the workforce. This type of objectives are increasingly important to the young generation, and their expectations towards employers are growing [26]. Understanding the manufacturing enterprise through the knowledge-based view leads to a number of practical key implications regarding the design of the information and knowledge management system and the organizational practices and ICT system architecture supporting it. For instance, impediments to knowledge sharing between the workforce should be removed, codifying and transferring tacit knowledge to explicit form supported, and social tools fostering e.g. the emergence of communities of practice introduced. All of these can take place in a manufacturing environment also naturally, but their potential is squandered with workflows, tools and processes that often do more to hinder than enable the relevant knowledge flows. These viewpoints come together in the concept of 'Self-learning manufacturing workplaces' which is one element of Smart Factories [13].

Self-learning workplaces require making data transparent by gathering, assessing and evaluating data from the machines and descriptions of services and processes, defining what patterns determine successful production and high product or process quality and transferring this as a knowledge to the manufacturer. Reoccurrence of problems will be prevented by systematically storing and sorting the production data and combining it with successful solutions – i.e. building an organizational memory system [27], and thereby enabling self-learning workplaces. [13]

3. Research approach

The research approach of this study can be categorized as a conceptual study. This doctrine of research is mainly based on previously formulated concepts and their analysis, but it can also include some empirical evidence and research findings. Conceptual studies do not need to present new theory as such, but rather bridge existing concepts, theories and disciplines, offering new insights and broadening the current thinking. They have a problem-solving focus and highlight especially the novelty aspects of the research, thus differing from pure reviews of extant literature [28]. The overall objective of the study is to capture workers' and organizations' needs and requirements for information and knowledge-based support in manufacturing, and to develop organizational and human-centered models to make manufacturing processes and cultures fit for the developed smart factory solution.

After the literature review on previously formulated concepts, the three-level approach was identified to illustrate the different levels of needs in manufacturing companies, which are depicted in Fig. 4. These levels are the management level (see e.g. ISA-95 level 4), organizational level (ISA-95 level 3) and worker level (ISA-95 levels 0-2). This study will emphasize especially what kind of data and information needs and flows are necessary from the workers' point of view on the shop floor. The three-level approach was chosen over established frameworks in view of this objective. While frameworks like PERA or ISA/95 are useful from an IT standpoint, the needs expressed by the manufacturing companies essentially have three varieties: organizational, process/system and most importantly, worker needs. These worker-level needs tend to be human (e.g. improved job satisfaction, engagement and motivation, safety and well-being, social status and fostered community, and decreased cognitive challenges), and fit poorly to other frameworks and often end up being underrepresented in enterprise integration and IT system development projects.

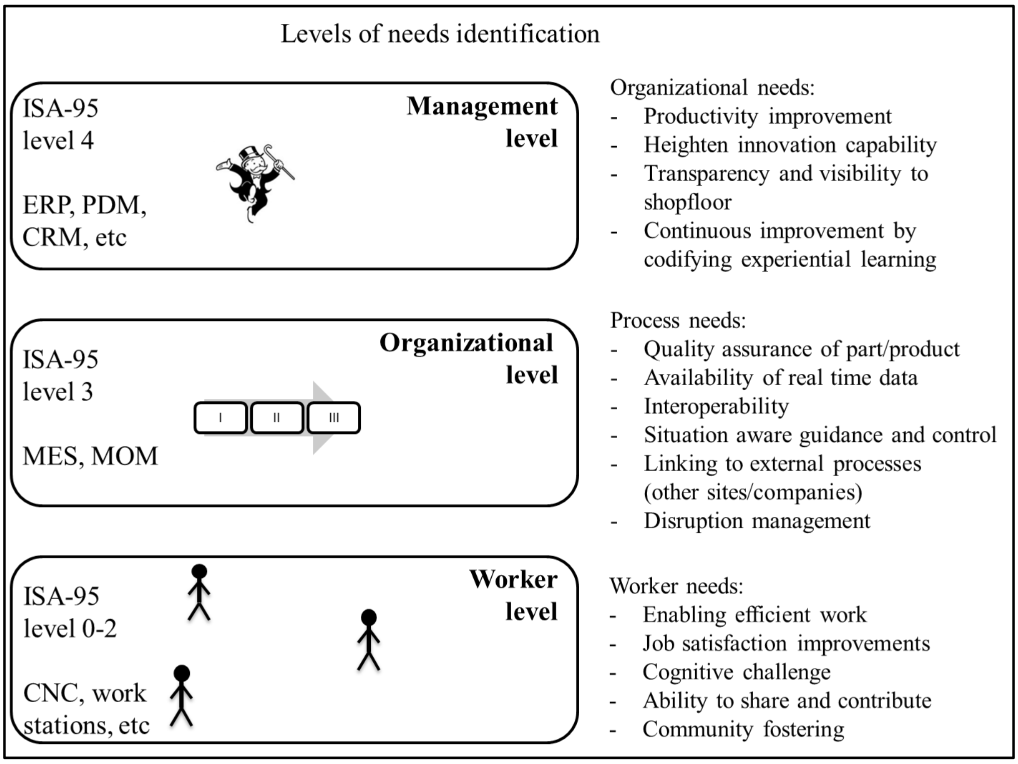

Fig. 4. Different levels of needs in manufacturing companies

In this study, the different levels of needs in manufacturing environment are recognized, as depicted in Fig. 4. At the worker level, the needs are usually comprised of such issues as healthy, safety, social status, respect, appealing [19], as well as needs for cognitive challenges and community fostering. Whereas, the needs of the management level are usually comprised of improvements in productivity, quality, costs and innovation capability. In the between, there are several needs at the organizational level or process level, where the needs are often related to e.g. availability of real time data, interoperability, guidance and control and disruption management.

This study is part of the theoretical background research for the on-going FACTS4WORKERS project, which develops and demonstrates workplace solutions that support the inclusion of increasing elements of knowledge work on the shop floor of factories. FACTS4WORKERS is a large-scale research project that puts the worker into the center of future-oriented production concepts in order to render manufacturing jobs more attractive and help Europe to become more competitive. Smart workers in those production sites will be ideally supported by information and communication technology in order to improve their daily work. The primary goal is to increase job satisfaction, but also improve the manufacturing process regarding flexibility, efficiency and reliability.

4. A conceptual framework for knowledge flows and performance improvements

In this section, a conceptual framework is created to link workers' and organizational needs to data and information requirements. Previous research has focused more on developing different kinds of integration models, where the focus has been in the top-down information flows from management to shop floor.

In Fig. 5 the perspective is on utilizing worker and shop floor knowledge at different levels of a company. The shop-floor knowledge remains a largely untapped potential asset to manufacturing companies. The production level is able to generate massive quantities of data from its systems, sensors and machines. The transparency and control enabled by integrating this data stream to enterprise level decision-making is one of the greatest motivations in developing more vertically integrated IT systems. However, to utilize the shop-floor knowledge properly requires the human inputs, that is, the tacit and explicit knowledge of the workers holds even higher promise. Supporting and facilitating the worker-centric knowledge flows can enable more efficient learning processes, higher job satisfaction and a host of other benefits both for the individuals and for the organization.

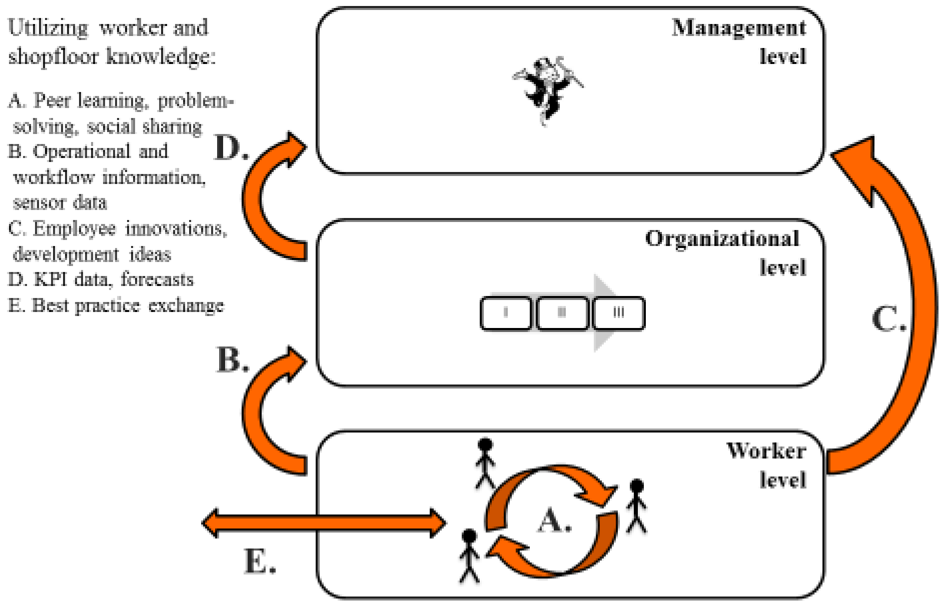

Fig. 5. Worker-centric knowledge flows

Simply enabling bottom-up knowledge flows is not enough to answer the needs of both the worker and the organization. Knowledge flows to the worker need to be enhanced in parallel. Manufacturing workers (especially in discrete production settings) require many types of data, information and knowledge, often unplanned and on demand in order to complete their tasks efficiently. Fulfilling these information requirements proactively by setting up and supporting the knowledge flows, as seen in Fig. 6, is one of the most effective ways to remove productivity barriers from current operations. Real-time access to knowledge on demand, support for collaborative problem solving and social sharing of work practices eliminate unnecessary time spent waiting or seeking documented instructions, while also improving job satisfaction. Especially noteworthy are the peer-to-peer knowledge flows on the shop-floor (A.) that are often unsupported by tools and neglected in top-down designed development projects.

Identifying and enabling the required knowledge flows within the manufacturing enterprise leads to performance benefits on multiple levels and by multiple mutually reinforcing mechanisms, presented in Fig 7. The first performance effect is a step change in productivity, resulting from removing inefficiencies, providing ready access to required data and information and enabling more precise control of the production process. While this is for most development projects the expected outcome and generally well quantified, other performance mechanisms are more important. The key benefit of focusing on enabling and supporting information and knowledge flows within the enterprise comes from dynamic performance improvement mechanisms at each of the levels of our framework: individual and organizational learning, process re-engineering and optimization, and finally, innovation.

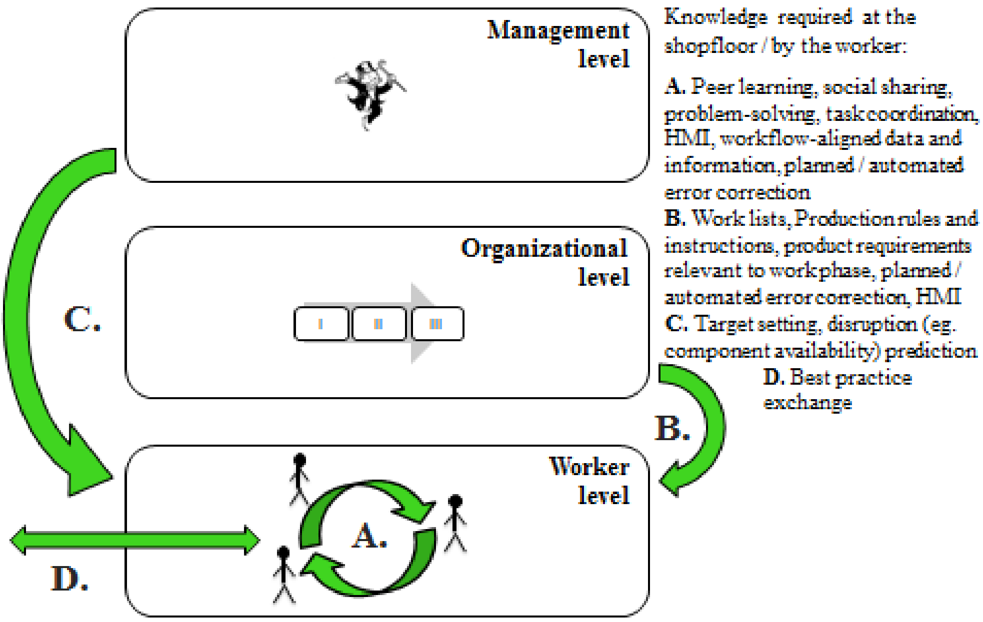

Fig. 6. Knowledge needed by workers

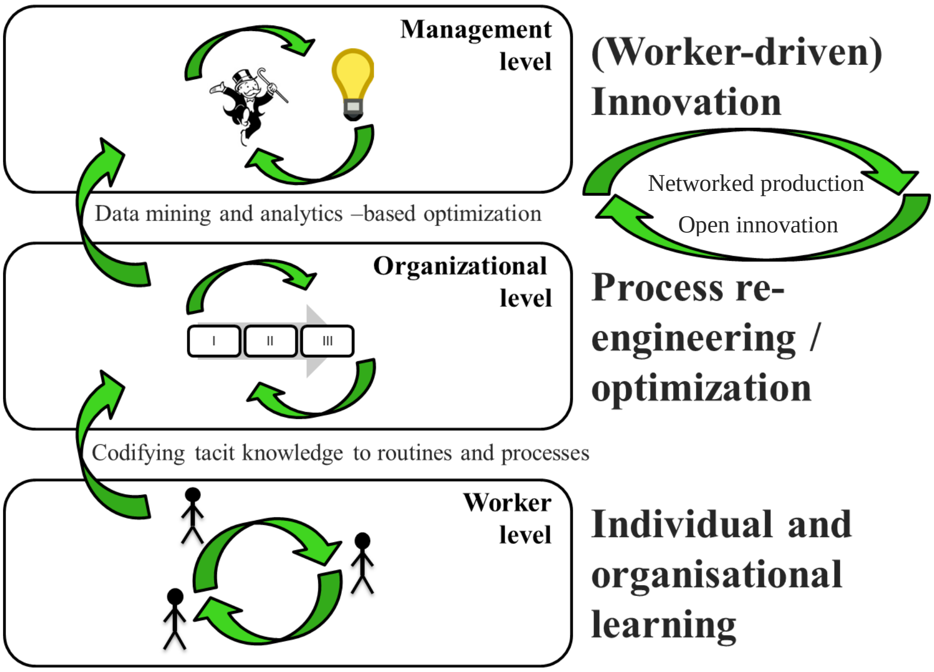

Fig. 7. Performance improvement mechanisms

At the worker level, especially supporting peer knowledge exchange, and group learning, problem solving and knowledge sharing, facilitates individual learning to improve skills and builds tacit knowledge. When shared with the work community, ingrained in routines and processes and gradually codified to explicit documented knowledge the individual learning and its benefits are partially socialized to the benefit of the entire organization; resulting in organizational learning [21]. At the organizational level renewal happens by readjustment of the extant processes through incremental optimization or more thorough process re-engineering. Better availability of information and utilization of knowledge from the production level allows precise control and fine-grained management of operations. Further enhancement may be sought by utilizing the masses of data generated by the production level by Big Data analytics, and data mining for more sophisticated optimization. Finally, at the management level the performance increase results from innovation that in turn is accelerated by the influence of worker ideas and inputs, production data and possibly even external inputs through open innovation within the production or supplier networks.

5. Discussion and conclusions

Manufacturing companies in the automotive industry are faced with a vast set of diverse demands, which are very strict, detailed and non-compliancy to any of them could lead to a loss or termination of business deals. Therefore, whenever any unexpected, unplanned or unsuccessful situation on the shop-floor arises, this may have a negative impact on business operations. This study provides an overview of how worker and organizational needs could better be linked with data and information requirements on the different organizational levels of manufacturing companies. We focus especially on vertical operations around manufacturing workplace instead of horizontal process development.

As theoretical and practical contributions of the study, we have created a conceptual framework and an approach to identify what kind of manufacturing data, information and when is needed by workers for their specific purposes. The framework identifies information and knowledge flows from and to required human-machine interfaces on different organizational levels. The elements of the framework are summarized in Fig. 8. In the worker level, sufficient and real-time information flows remove productivity barriers and support learning of individuals and groups. By identifying and codifying workers' tacit knowledge into routines and processes of the whole organization, learning and performance improvements can be achieved at organizational level as well. This real-time information together with tacit knowledge creates the basic foundations for process re-engineering or incremental optimization from the worker's point of view.

Knowledge flows between the worker and management level play also a significant role in developing worker-driven process or product innovations. Ideas and inputs from the shop floor for improving the work processes and practices are in the key position when seeking for an increase in job satisfaction and productivity. In order to obtain and filter relevant knowledge more efficiently and effectively from worker and organizational levels, tools for data mining and analytics are utilized to support decision-making at management level.

Supporting learning processes and continuous change can lead to establishing routines for change also called "metaroutines" [29] that lead to higher organizational flexibility and proficiency in managing organizational change and have been connected to higher performance, especially in highly dynamic environments [30]. Our argument is that information system solutions may facilitate more effective metaroutines by integrating the worker level to the essential knowledge flows and allowing them to contribute even more effectively during routine production [29]. However, excessively fast change can also prove detrimental to organizational performance. Periods of stability are required to allow for learning effects and establishing organizational routines that transform collective experience into performance [31, 32]. Utilizing ICT solutions to support an accelerated learning process may provide a sustainable competitive advantage in dynamic environments where the pace of adaptation and renewal that an organization can effectively sustain (without e.g. undue cognitive stress to the worker), in other words dynamic capability [32], is a key competitive factor. Thus we argue that our concept, backed with suitable ICT solutions, may allow a competitive advantage in upgrading the organizational capability for rapid adaptation and sidestepping the efficiency-flexibility tradeoff [29].

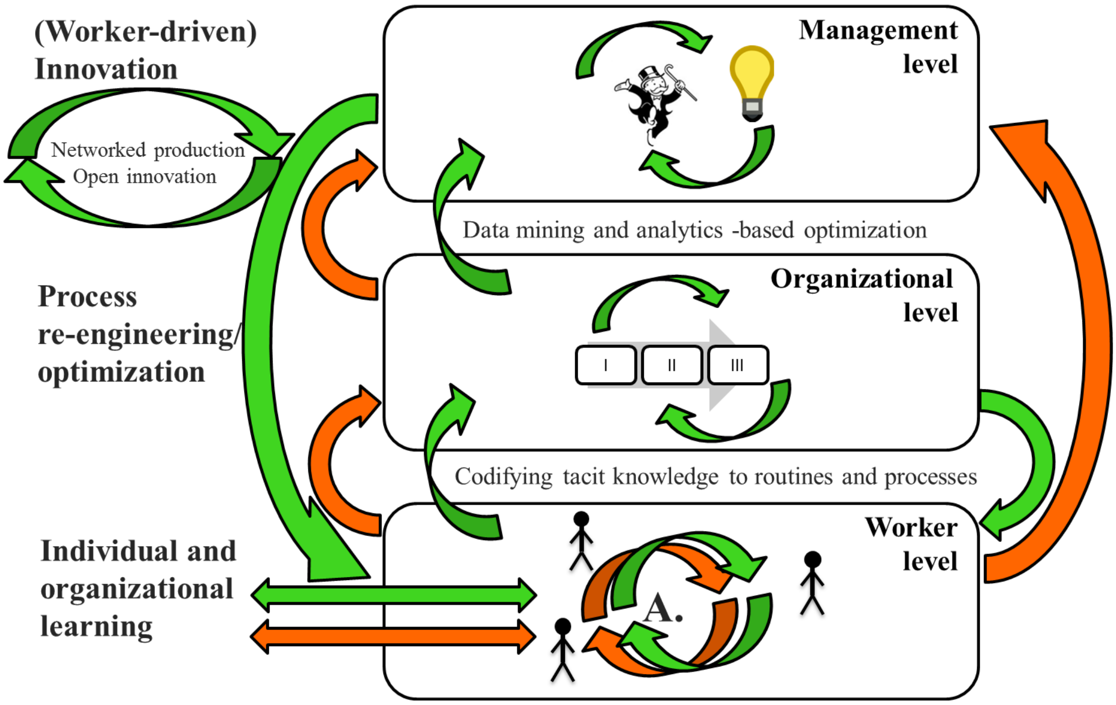

Fig. 8. The conceptual framework for knowledge flows and performance improvements

The study highlights that merely concentrating on horizontal objectives, information flows and performance improvements at each level of a company are not enough, but when achieving also vertical targets from the workers point of view, it enables also organizational learning and increases productivity. Further research is needed to operationalize the conceptual framework for future smart factories, with an intelligent, self-learning optimization process, the use of an advanced system/tools, required for collecting product, resource and process data, with a user-friendly interface for the shop-floor employees. Their implementation could aid manufacturers to acquire a tighter intelligent and interactive control over workplace, work safety, active protection of workers and economic benefits, and enable workers to actively monitor and respond to any problems that might arise regarding the machinery and devices they use. In addition, an empirical validation of the conceptual framework is needed. A basic question is how new IoT technologies could wisely be applied in supporting workers' desires by timely and reliable information, also meeting the needs of organization and processes.

Acknowledgements

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